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CENTER FOR DEVICES AND
RADIOLOGICAL HEALTH

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ADDITIONAL GUIDANCE FOR TESTING IMMUNITY TO RADIATED ELECTROMAGNETIC FIELDS - INFANT APNEA MONITOR STANDARD

ADDITIONAL GUIDANCE FOR TESTING IMMUNITY TO RADIATED ELECTROMAGNETIC FIELDS

SECTION (c)(7)(ii)(b) - RECOMMENDED TEST METHODS - ELECTRICAL, ELECTROMAGNETIC COMPATIBILITY, IMMUNITY, RADIATED ELECTROMAGNETIC FIELDS

The test method specified for immunity to radiated electromagnetic fields is intended to evaluate the performance of the monitor under radiated electromagnetic conditions similar to those it is likely to experience in actual use. This method takes into consideration the compromises which must be made in making measurements in existing EMC test facilities, particularly at the lower frequencies (10 to 200 MHz). In actual clinical and home use, the apnea monitor's cables are often extended further than is practical in an indoor test facility. The non-inductive, serpentine cable configuration that is specified in the test method exhibits low-frequency resonances such as those that occur in fully-extended cables, yet is capable of fitting in relatively small EMC immunity test systems. Because the use of serpentine cable bundles may not precisely simulate radiated RF coupling to fully-extended cables at frequencies whose wavelengths are greater than the size of the serpentine cable bundles, the open-area test shall take precedence between 10 and 200 MHz.

Commonly-available electromagnetic field absorbing material used in indoor RF test facilities cannot completely eliminate electric field distortions such as non-TEM modes and exposure-system resonances at lower RF frequencies. Therefore, the degree of distortion of the magnitude and spatial distribution of the electric field shall be determined after the uniformity of the E-field of the exposure region is disturbed by insertion of the apnea monitor. This determination is not required in anechoic chambers that are fully lined with effective (-10 dB in the frequency rang of interest) reflection-suppressing absorber or in outdoor, open-area exposure facilities, since these systems do not possess the capability to resonate or sustain non-TEM (higher-order) modes.

To assess distortion of the exposure field when the monitor under test is in place, measurements shall be made in a second test plane (Test Plane 2) that is parallel to Test Plane 1 and spaced at a distance from Test Plane 1 appropriate for the test frequency range (see Table II). To accurately measure the E-fields to which the apnea monitor (including its cables) is exposed, an instrument (E-field probe) shall be used that minimally perturbs the fields it is measuring (Bassen and Smith, 1983). Such a probe shall be used to spatially measure (map) the electric field strength in both Test Plane 1 and Test Plane 2 (see Figure 1).

Test Plane 1 is mapped with the monitor removed from the exposure field, while Test Plane 2 is mapped separately and with the monitor in place as shown in Figure 1. Since the electric field strength is always zero at the surface of a conducting object, a finite separation distance must exist between the two test planes. Ideally, an equation would be used to establish a continuously-varying, frequency-dependent separation distance. Instead, for simplicity, three discrete separation distances are specified in Table II of section (c)(7), each applicable to a portion of the test frequency range. This table specifies conditions that minimize E-field distortion and measurement errors when the monitor (including cables) is present in the exposure field. These errors are caused by reflections due to the presence of a conducting object and quasi-static coupling between a conducting object and the antennas of the E-field probe.

REFLECTIONS DUE TO THE PRESENCE OF A CONDUCTING OBJECT

E-field distortions caused by reflections of the electric field by conducting objects are most significant when the object is larger than one-half of the wavelength of the exposure field's frequency. If the largest linear dimension of the surface area of an object exposed is much smaller than one wavelength (an "electrically small" object), reflections will be relatively insignificant. The simplest case to account for reflections is a plane wave (TEM mode) which strikes an "electrically large" conducting surface. This surface is a simplified model of the object under test. At a distance of 1/2 wavelength in front of the conducting surface (between the distant RF source and nearby conducting plane), the E-field is zero. At a distance of 1/4 wavelength from the large conducting object, the E-field is twice the value that exists when no conducting object is present. Therefore, in the case of an electrically-large conducting object, the optimum separation distance between the reflecting object under test and the E-field sensor is 1/8 wavelength. It should be noted that below 200 MHz, most apnea monitors, including their serpentine cable bundles, are "electrically small" and do not cause significant field distortions due to reflections.

For the frequency range os 200 to 400 MHz, the separation distance that represents 1/8 wavelength of the mean frequency (300 MHz) of this band is 12.5 cm. In the 400 to 1000 MHz range, the distance corresponding to 1/8 wavelength of the mean frequency (700 MHz) is 5.4 cm. For both of these bands, the E-field distortions have been evaluated for reflections from electrically-large objects exposed to the lowest and highest frequencies in these bands. At a distance of 12.5 and 5.4 cm from the equipment under test for these two frequency bands, respectively, reflections at the ends of the frequency band are different in magnitude from reflections at the mean of the frequency band by no more than several dB.

QUASI-STATIC COUPLING BETWEEN THE CONDUCTING OBJECT AND THE ANTENNA OF THE E-FIELD PROBE

A second phenomenon that causes measurement errors of RF electric fields in the presence of conducting objects is quasi-static (capacitive) coupling. This coupling between the conductive object and the measurement probe is relatively independent of the exposure field's frequency. Reactive near fields, which dominate in this type of coupling, exist only at distances that are much less than on wavelength and are smaller than the size of the conducting object. An analytic evaluation of the measurement errors due to quasi-static coupling between an E-field probe and the apnea monitor under test is as follows:

The largest conducting object of the system under test is assumed to be a set of several densely-wound cables (serpentine cable bundles), filling the entire 0.75 x 0.75 meter surface of the foam block (as specified in section (c)(7)). The surface area of this conducting object is much larger than the area occupied by the RF-sensing elements (antennas) of the E-field probe. Given the large, unchanging size of this cable array, the size and position of the E-field probe's sensors significantly affect the magnitude of coupling errors (Bassen, 1990). A coupling error of less than one dB results if the separation distance between the E-field probe's sensors and the cable array is several times greater than the diameter of an imaginary spherical volume containing all conducting portions of the sensors. The data were used to determine the test-plane separation distances specified in Table II. Broadband, non-perturbing E-field sensors for measurements of 1 V/m or more are commercially available. These probes typically occupy a spherical volume with a diameter of less than 6 cm.

CONNECTION OF EQUIPMENT TO THE APNEA MONITOR DURING RADIATED IMMUNITY TESTING

Care must be taken in the use of functional testing devices and EMC diagnostic instrumentation during radiated immunity testing. When patient simulators or test equipment that is not part of the monitor is connected during radiated immunity testing, extraneous RF voltages can be introduced into the equipment under test. Therefore, battery operation of patient simulators, fiber-optic links (Bassen, 1978), and any other method that minimizes extraneous RF coupling to the apnea monitor should be used during radiated immunity testing.

A brief explanation of the acceptable exposure methods for RF immunity testing is presented below:

(1) OPEN-AREA TEST SITE. Open-area testing has been the method of choice for EMC emissions testing because of the uniformity of the electric field. This test method also represents the most accurate means for performing apnea monitor radiated immunity testing because the monitor's cables can be extended as they are in normal use. This test method usually reveals cable resonances at low frequencies (below 50 MHz) that may not be seen using other test methods. In order to comply with various national and international laws prohibiting radiated interference to radio communications, restrictions may exist in most populated areas. Therefore, specific frequencies (emergency and local broadcast) must be omitted from open-area tests. For apnea monitor development testing, this test method can always be used at the following Industrial, Scientific, and Medical (ISM) frequencies, where minimal transmitting restrictions

exist: 13.56, 27,12, 40.68, and 915 MHz. For open-area testing, the total ambient field strength (due to signals other than those generated by the EMC field-generating antenna) should be measured during the test to assure that it is at least 20 dB below the immunity limit.

(2) ANECHOIC CHAMBER. A fully anechoic chamber consists of a screen room, fully lined with electromagnetic field absorbing material on the ceiling, floor, and all walls. Standing waves in the empty chamber should be less than 6 dB (peak to peak) along the axis of propagation under plane-wave exposure situations. Conventional anechoic chambers are less effective at lower frequencies (e.g. less than several hundred Megahertz, depending on chamber size). Particular care shall be taken in establishing an area of uniform exposure field at these lower frequencies. Measurements shall be made to quantify the spatial distribution of the E-field in the area of uniform exposure field.

(3) PARALLEL PLATE LINE. The parallel plate line is a tapered-input, balanced transmission line with two flat, parallel conductors. As long as the separation between plates does not exceed approximately 1/4 wavelength, only a single transverse electric field mode exists. This

provides a simple means of generating a linearly polarized, spatially uniform electric field with minimal radiated energy. This method is best suited for frequencies below about 30 MHz, where large objects (up to 1/3 of the plate-separation distance) can be placed between the plates, without significantly altering the characteristics of the E-fields between the plates. Problems in a parallel-plate line operated at high frequencies include radiation of energy, causing the actual field strength to be less than the theoretical field strength. Also, higher-order modes exist, causing significant exposure-field nonuniformities.

(4) TEM CELL. The transverse electromagnetic (TEM) cell is an unbalanced parallel plate line that is fully enclosed (forming a "square coaxial line") with the top and bottom plates forming an RF ground. The RF-energized center conducting plate establishes a TEM mode field between this plate and the ground plates. The TEM cell is similar in performance to the parallel plate line, except that stray radiated fields are eliminated. Problems of a TEM cell operated at higher frequencies include resonances and occurrences of higher-order (non-TEM) modes. However, absorber loading of modified TEM cells has produced units usable from dc to several GHz. Objects placed in

a TEM cell should occupy no more than one third of the separation distance between the center plate and one of the outer plates.

(5) SCREEN ROOM. Screen rooms have been traditionally used to irradiate large and small electronic devices for RF immunity testing over a wide range of frequencies. Various antennas are used to illuminate the screen room and its contents. The room has completely conducting walls and doors. The electromagnetic reflections from the walls of this room produce E-field spatial nonuniformities, multiple electric and magnetic field modes, changing field polarizations, and large standing waves at many, often unpredictable locations. Therefore, multiple point mapping of the electric field is essential when using this exposure system for radiated immunity testing. In addition, screen rooms act as resonant cavities at several frequencies. At these resonant frequencies, spatial and amplitude variations of the electric field within the room can exceed 40 dB. However, by experimenting with the placement of the antenna and the equipment under test within the room and by carefully monitoring the electric field distributions with the equipment under test in place, screen rooms can be used to produce

practical, usable results, especially for immunity testing at frequencies below about 30 MHz.

(6) SEMI-ANECHOIC CHAMBER. This exposure system is essentially identical to the screen room, except that microwave absorber is placed in strategic locations on the conducting surfaces of the walls, floor, and ceiling of the screen room to reduce reflections and non-TEM higher-order modes in the chamber. The floor is usually a conducting ground plane, with RF absorbing material placed on the floor between the RF source and the equipment under test. At frequencies below the effective range of the absorber, field nonuniformities in excess of 6 dB exist. However, by experimenting with the placement of the antenna, the equipment under test, and the absorber within the room, an area of uniform field distribution can be established over a range of frequencies.

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